Development Roadmap of an Evolvable and Extensible Multi-Mission Telecom Planning and Analysis Framework[1]

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Abstract—In this paper, we describe the development roadmap and discuss the various challenges of an evolvable and extensible multi-mission telecom planning and analysis framework. The ability to re-use the spacecraft and ground telecom behavior models and the common software utilities in mission adaptations has contributed significantly to the development and operation in terms of model consistency, analysis accuracy, and reduced effort. This translates into shorter development time and cost savings for the individual missions. In this roadmap, we will address the design principles, technical achievements and the associated challenges for the following telecom analysis tools development: (i) Telecom Forecaster Predictor (TFP), (ii) Unified Telecom Predictor (UTP), (iii) Generalized Telecom Predictor (GTP), (iv) Generic TFP, (v) Web-based TFP, (vi) Telecom Application Program Interface, and (vii) Mars Relay Network Planning Tool (MRNPT).

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1. INTRODUCTION

In this paper we describe the development roadmap, and discuss the various challenges of an evolvable and extensible multi-mission telecom planning and analysis framework. The multi-mission core development is primarily funded by the Deep Space Mission Subsystem (DSMS) of the Interplanetary Network Directorate (IND), and mission adaptations are funded in general by the individual projects.

The fundamental design framework for the telecom analysis tools is based on the following four principles: (i) The *Multi-Mission Infrastructure* allows us to establish common telecom models, software components, and interfaces that can be shared by different missions. This helps us to shorten the development life cycle as well as reduces the development cost. (ii) The *Computational-based Software Architecture* enables the usage of advanced mathematical and optimized software algorithms during both the development and operational phases. (iii) The *Analysis Framework for Mission Lifecycle Development* provides a seamless transition of spacecraft telecom models from pre-phase-A through phase E since all DSN ground performance models and most of the software utilities share the same baseline. (iv) Finally, the *Modular Design* allows rapid re-configuration and extension of existing functions to build new tools and to anticipate various mission needs.

Based on these principles, we have developed a series of tools to fulfill the needs for a set of powerful, easily adaptable, multi-mission telecommunications analysis tools. The first and core development of such tools is the Telecom Forecaster Predictor (TFP), which provides the link analysis for between a deep space station and a spacecraft via a graphical user interface of telecom parameters. Due to the increasing demands on using non-DSN tracking stations to support mission critical events, non-DSN station models are gradually being added to the TFP baseline. Currently five JPL missions use TFP as their operational link analysis tool, and adaptations exist for 13 missions.

The development of TFP has led to a number of useful byproducts. Particularly its batch mode counterpart, the Unified Telecom predictor (UTP) was developed to generate telecom predicts to support Deep Space Network (DSN) tracking and telecom resource profiles to support project mission planning.

To allow the users to specify a link between a spacecraft and another general communication entity, a new tool called the Generalized Telecom Predictor (GTP) was developed. To support the UHF link (proximity link) analysis for the Mars Exploration Rovers (MER), GTP computes the link

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performance between the MER-A and MER-B rovers and the Mars Global Surveyor (MGS) and the 2001 Odyssey orbiters. In general GTP can also model the orbiter-to-orbiter link as well as the lander-to-lander link.

Additional extension and adaptation of TFP include 1) the TFP generic model to support early mission design phase, 2) the Web-based TFP to support remote access of the telecom planning and analysis capabilities, and 3) the telecom Application Program Interface (API) that encapsulates the telecom analysis models into C-callable libraries to support co-simulation with other system and subsystem models.

Leveraging on the success of TFP, UTP, and GTP, a new effort was proposed and launched in September 2002 to develop the Mars Network Relay Planning Tool (MRNPT). This development introduces a mathematical planning approach that models the link resources and operational constraints, and casts into a standard linear and non-linear constrained optimization problem. The MRNPT consists of a relay analysis framework that interfaces with the TFP and GTP models. The MRNPT generated preliminary link-optimized support plan between lander and orbiter, lander and Earth, and orbiter and Earth. The support plan can then be used as a basis for manual and automated refinement and negotiation to support end-to-end Mars mission data delivery. The details of these telecom analysis tools will be discussed in subsequent sections.

This paper is structured as follows. In Section 2, we discuss the design principles that we adopted in the telecom tools. We describe the development milestones of the telecom tools that are in used or are under development in Section 3. In Section 4 we discuss the various challenges to maintain a multi-mission baseline to support ongoing customers both inside and outside JPL, and at the same time allows the continual infusion of advanced analysis, modeling, and optimization techniques to the development. We end the paper in Section 5 with the discussion of future development plan and some philosophical issues.

2. DESIGN PRINCIPLES

In the past, telecommunication analysts at the Jet Propulsion Laboratory (JPL) would build their own tools for mission support. These tools would differ in architecture, user interface, and software basis[3], even though their primary purpose was the same. Data and formulations common to all missions were not shared which resulted in a duplication of effort. Modeling differences and errors often went uncorrected because there was no convenient baseline for comparison.

As JPL continues to fly smaller spacecraft in more frequent low-cost missions, it is a luxury for each flight mission to fund its own link analysis tools development. There was a need for an easily adaptable telecommunications tool for supporting a wide variety of Deep Space missions.

Also traditional telecom planning and analysis[4] is, by and large, limited to single point, worst-case scenario analysis of a static communication link, especially during quick fast turn-around analysis. Communications during spacecraft dynamic events (which are usually critical) like launch, trajectory correction maneuver (TCM), Mars orbital insertion (MOI), and entry, descent, landing (EDL) are usually not sufficiently characterized a-priori, and rely on the intuition of experienced system engineers (the gurus) in mission design and in mission operations. When detailed analysis is called for, much effort and time are needed to coordinate data products among various subsystem teams (e.g. attitude and navigation) to support each mission scenario.

To overcome the above shortcomings and to contemplate future mission needs for high-fidelity system-wide modeling, simulation, and design trade-off, we adopted the following design principles on the next-generation telecom tool development:

Multi-Mission Infrastructure

We establish a multi-mission telecom model and software infrastructure that facilitate the sharing of model and software components and interfaces between missions. This shortens the development life cycle and reduces the development cost. Mission adaptations are usually completed and tested within a couple of work-months. This multi-mission framework also provides a mutually beneficial setup between telecom analysts and tool developers for continual model and software refinement. Improvements and new features as a result of updates from one mission can be assimilated by all (if the multi-mission core change) or easily ported to other mission adaptations.

Computational-Based Software Architecture

The telecom tools are built upon the popular MATLAB, which is a technical computing environment for high-performance numerical computation and visualization. MATLAB is widely used by the scientific community. The telecom models are implemented in MATLAB and take full advantage of MATLAB's extensibility. MATLAB's script language is optimized for vector/matrix computation, which is ideal for telecom time-series analysis. Also it provides a rich set of built-in and well-tested mathematical algorithms (MATLAB functions and toolboxes) and a comprehensive software development environment[5] that facilitate rapid

[3] Previous tools were based on Microsoft® Excel or PERL.

[4] This refers to the traditional Design Control Table (DCT) approach of link analysis, which tabulates the gain and loss of a communication link in a score sheet to provide overall system insight.

[5] MATLAB code is portable across all popular computer platforms (SUN, PC WIN/NT/Linux, and Mac). It offers easy to use GUI

scientific application development. This architecture supports the simultaneously incorporation of advanced mathematical and software algorithms into operational software development process.

Analysis Framework for Mission Lifecycle Development

Though the telecom tools were originally designed to support high-fidelity link analysis in phase-E, the multi-mission core, which consists of DSN ground performance models and common software utilities, can be used in earlier mission phases to support design iteration (see generic model description in Section 3). This analysis framework allows a seamless transition of spacecraft telecom models from pre-phase-A through phase E, but still uses the same DSN ground performance baseline.

Modular Design

The telecom tool architecture de-couples visualization, modeling, interface, and back-end processing functions to allow plug-and-play of various functions and extensions. This allows rapid re-configuration and extension of existing functions to build new tools and to anticipate various mission needs.

The development roadmap of the telecom tools is summarized in Figure 1. A detailed description of the development history that demonstrates extensive model and software reuse, integration, and planned evolution is given in Section 3.

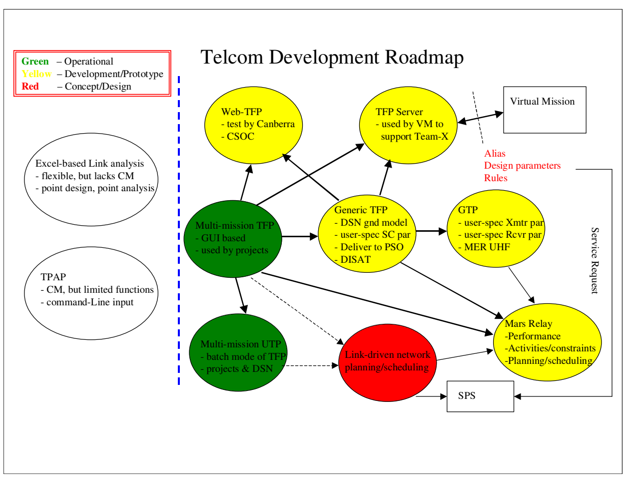

Figure 1 Telecom Tools Development Roadmap

3. DEVELOPMENT MILESTONES

The TFP, UTP, GTP, and MRNPT are mainstream development efforts that address different aspects of communication planning and analysis needs. To contemplate the increasing demands of integrated mission design, automated trade-off analysis, and progressive design optimization, we initiated a number of novel modeling and interface development efforts. These developments effectively utilize the high-fidelity telecom models to support mission operation scenario simulations and design iterations.

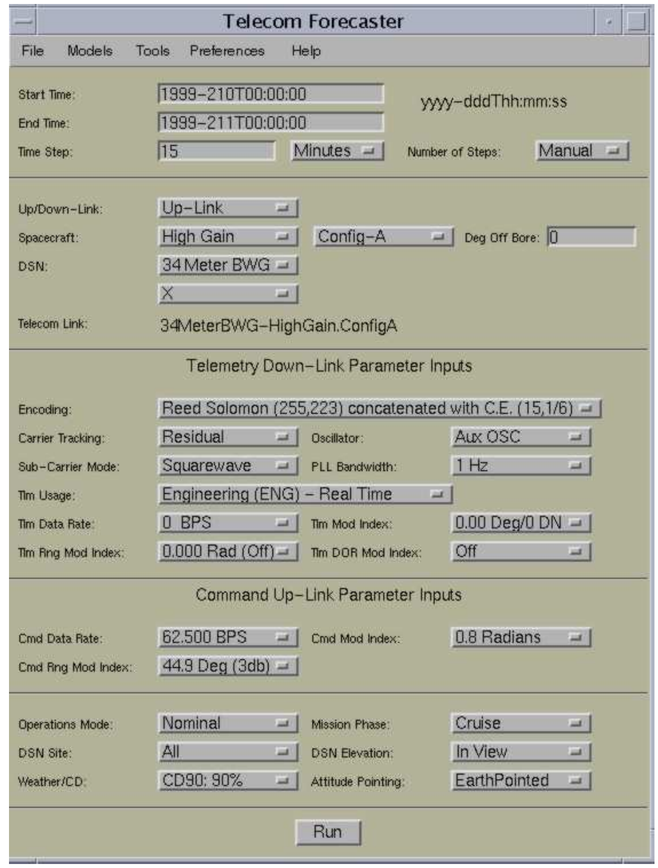

Figure 2 Sample TFP GUI

Telecom Forecaster Predictor

The TFP analysis tool [1] is built upon the popular MATLAB computing environment to support mission telecom planning and analysis. It allows novice users and operators to use the official models with pre-set configurations, and allows advance users to customize their own TFP sessions without changing official versions. Inputs are entered through the TFP's main graphical user interface (GUI), which has a characteristic look-and-feel independent of mission adaptation. The building blocks of the TFP are models (specialized MATLAB scripts) that are organized in a logical fashion. Model hierarchy is traceable through an automatically created model tree, and individual models can be examined using the TFP's model editing tool. After execution, outputs are viewable in plot or tabular[6] form, and design control tables provide snapshots of link performance at a single time point.

builder tools, C/C++ and FORTRAN interfaces, excellent graphing capabilities, and a C/C++ compiler that translate MATLAB code into MATLAB independent C/C++ source code and executable.

[6] Time-stamped data can be saved in comma-separated variable (CSV) form for export to other applications like Microsoft® Excel.

The TFP model libraries are analogous to MATLAB toolboxes. Multi-mission models reside in an area accessible to all missions, whereas mission-specific models are stored in individual mission areas. Models are easily modified or replaced which allows great flexibility. Existing mission models are often reused or used as templates by new missions that accelerate development. A screen shoot of TFP GUI is given in Figure 2.

Unified Telecom Predictor

The UTP tool is the batch mode counterpart of TFP. It re-uses the same mission and Deep Space Network (DSN) models and interfaces as TFP. This reduces development and maintenance cost, and ensures that there is no ambiguity and discrepancies between the projects' and the DSN's analysis. In the future the UTP tool will be used in the Service Preparation Subsystem (SPS) to produce telecom link predictions to configure the DSN for tracking support. UTP also provides data rate capability files (DRCF) to support mission planning and resource allocations. Figure 3 shows how the GUI-based TFP and the batch mode UTP share the same telecom models to support their respective functions.

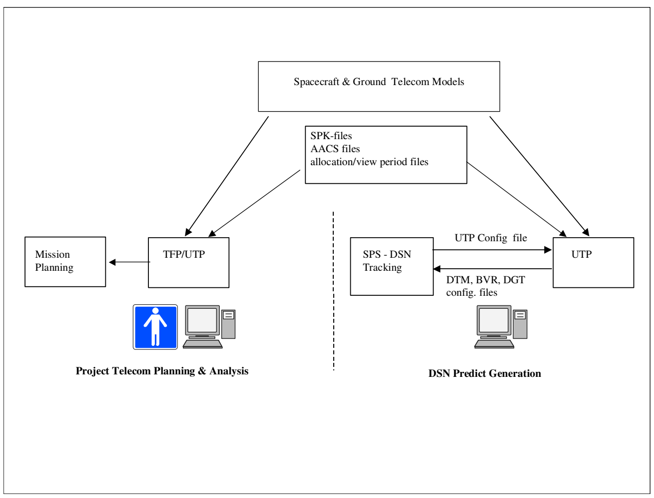

Figure 3 Common Models and Interfaces

Generalized Telecom Predictor

The GTP tool is a generalization of the operational multi-mission TFP tool. What distinguishes GTP from TFP is that instead of using DSN or other ground station as a ground-based communication node, GTP assumes a link between two generic communicating elements, each of which can be transmitting and receiving. Each element can be a spacecraft in-flight, a lander or a rover on the Planet surface[7]. GTP addresses the same fundamental telecommunications problem of allocating power amongst carrier and data channels while meeting threshold conditions with a certain degree of confidence. The carrier threshold must be met in order for the receiver to acquire the signal. The data threshold is driven by bit-error-rate requirements imposed by the project. Power is divided between the channels through the selection of modulation indices. Analysis must be performed to book keep the gains and losses in a telecommunications link to verify that the thresholds are met.

GTP shares the same look-and-feel, design philosophy, and software architecture as TFP. A screen shot of the GTP GUI is shown in Figure 4. GTP inherits the trajectory and attitude interfaces and many modeling and software functionality from TFP. Each generic communicating element (includes transmitting and receiving models) in GTP allows user to input and save the values of a set of telecom parameters that typically characterizes the communication behavior of that element. Each element also has its own trajectory and attitude interfaces. The GTP framework provides the analysis and visualization functions of a generic transmitter-receiver link.

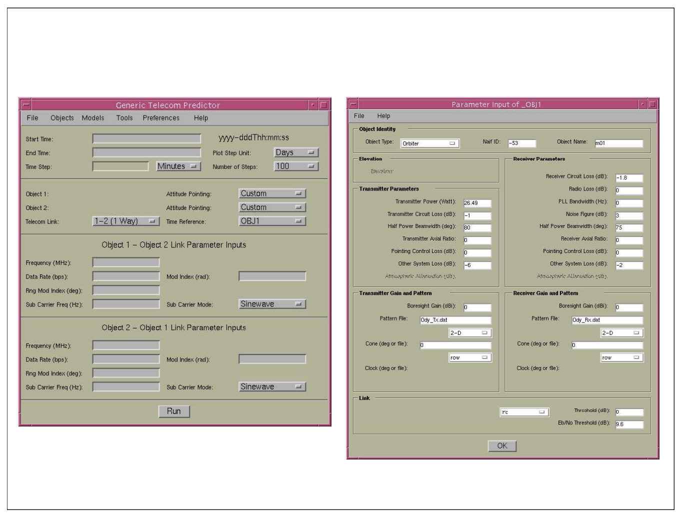

Figure 4 Sample of GTP GUI

Mars Relay Network Planning Tool

The Mars Relay Network Planning Tool (MRNPT) is currently being developed to support the end-to-end data delivery planning and analysis for a Mars communication network consisting of multiple surface elements, orbiters, and Earth stations. MRNPT's objective is to determine an optimal plan that will maximize the network throughputs with minimal communicating time and subject to various operational, telecom, and deep space communications constraints. The design approach has three distinct characteristics: 1) the client-server software architecture, 2) the modeling and simulation environment of the end-to-end network link performance and activities, and 3) the planning and scheduling methodology that optimizes the network resource usage subjected to various operational constraints.

The modeling and simulation environment support three

[7] If one end of the communication link is an Earth station, it should be handled by the Telecom Forecaster Predictor (TFP) with either specific spacecraft model or generic spacecraft model.

types of modeling – link resource, spacecraft dynamic events, and operation constraints.

- Link resource refers to the statistical link performance between two communication elements (surface assets, orbiters, and Earth stations. The link resource, which is expressed as supportable data rate or as estimated data volume during a pass, is computed using the operational TFP and GTP models. A sample timeline of link resource is shown in Figure 5. The MRNPT accesses these models via a C callable API as described later in this Section. The interface between MRNPT and TFP and GTP is depicted in Figure 6.
- Spacecraft dynamic events refer to the nominal and off-nominal spacecraft orientations and maneuvers performed by the communication elements that have direct and indirect impacts on the link. These events can be quiescent or dynamics. The two non-telecom factors that affect the link most are the range between the two communication elements and their corresponding antenna pointing.
- Operation constraints refer to physical laws, geometric constraints, hardware limitations, mission requirements, mission priority, policy requirements, and other factors that restrict the availability and operation of a link. The in-view and out-of-view periods between communication elements are governed by the occultation model adjusted by the light-time delay, and the shape, size of the celestial bodies in the solar system. Onboard data storage limits the amount of data to be transferred. Mission activities like instrument checkout, calibration, and science observation might mandate real-time communication at specific time and for specific duration. Mission priority imposes a biasing weight in the planning and scheduling of resource to service multiple spacecraft. Safety policy establishes a minimum elevation angle that affects the effective tracking time. Requirements on end-to-end data delivery latency depend on the criticality of the data. As shown in the subsequent sections, many of the above constraints are relationships between objects that can be formalized mathematically in the form of linear and non-linear systems of inequalities. Also the in-view and out-of-view periods between the communication elements reduce the continuous timeline into a finite set of possible contacts or passes within a given planning horizon.

The modeling of link resource, spacecraft dynamic events, and operation constraints provides an idealized view of the Mars network system behavior and the interaction between the communication elements and the environment. This modeling setup yields a constrained optimization problem, whose objective(s) could be minimizing the communicating time, or maximizing data throughput, or both. Like most optimization problem, which is usually NP-complete, the planning horizon (timeline) is limited by the computation power and the size of the search space. One approach to effectively extend the planning horizon is to apply the communication-specific geometric and operational relationships prior to the constraint optimization process to reduce the search space. Recent work [3] indicates that this approach is very promising. The simplified constrained optimization problem is then solved using commercial-off-the-shelf software (ILOG, MATLAB) or JPL in-house optimization tools (ASPEN, TIGRES). This design approach for a relay link network in general provides better link configuration and schedule timing information. This results in more favorable elevation angles and higher supportable data rates, thus requiring less track time per spacecraft on the average.

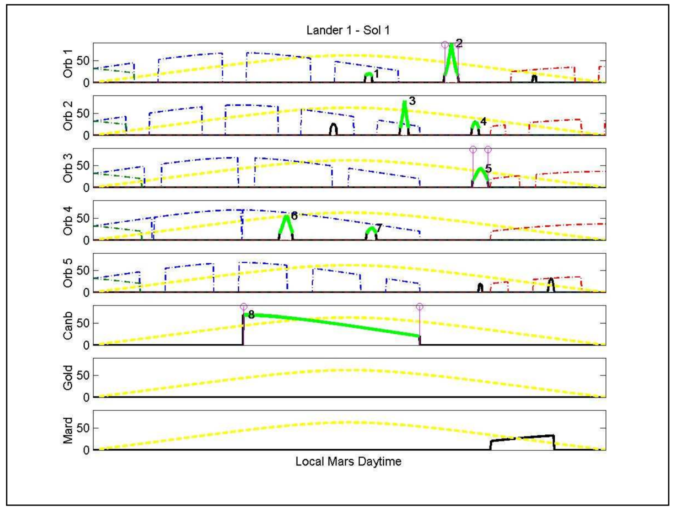

Figure 5. Considered passes from Lander 1 to the five orbiters and the DSN stations are highlighted and numbered.

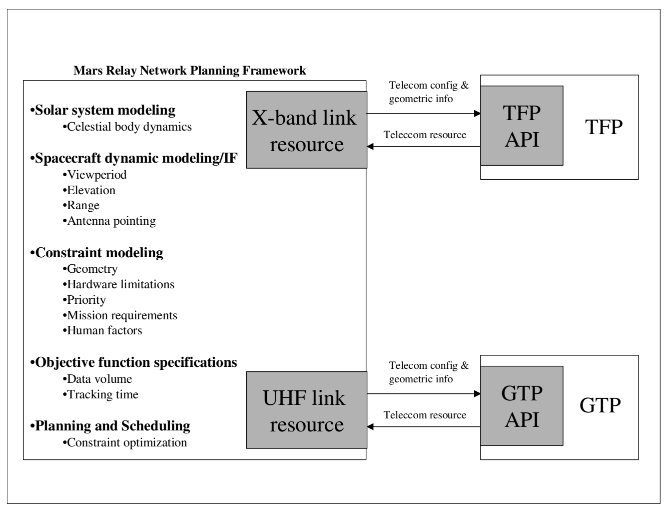

Figure 6 The Interface between MRNPT & TFP/GTP

Others Auxiliary Model and Interface Development

- Generic Telecom Forecaster Predictor - The Generic TFP is a telecom design and planning tool that missions can use in the early phases when detailed information of the spacecraft is not known. The spacecraft models are “generic” in nature, and are easily re-configurable for what-if analysis. Examples of telecom design parameters for trade-off are power consumption, antenna size and type, optimal set of data rates and their corresponding modulation indices. The Generic TFP is not meant as a replacement for the mission specific TFP, rather, as a step towards them. As such, the appearance and interface of the Generic TFP closely parallels that of the mission specific TFP's. Both Generic TFP and mission-specific TFP share the same common software framework and the same DSN ground performance model that is 810-5 compliance [5].

- WEB-Based Telecom Forecaster Predictor – The original TFP is a versatile telecommunication link analysis tool that requires the use of the commercial-off-the-shelf (COTS) software MATLAB. Over the years, we continue to support a diverse user community at JPL and Lockheed Martin (LMA), and maintain different versions of the software based on users' needs. There is an increasing desire from the user community to have easy access to the most up-to-date spacecraft and ground models but without much effort of frequent delivery and upgrade of the software. This requires a centralized telecom server that supports (a) remote access to the TFP tool, (b) remote software and model maintenance and update, and (c) no third-party software licensing. The Web-based TFP was developed to fulfill these requirements. It has all the same functionality as the original TFP, plus additional modeling and software features. The web-based TFP is implemented with HTML, JavaScript, XML, MATLAB, and MATLAB-Web Server. The web-based TFP is designed to be as user friendly as the original TFP intends, and generates the same output data products as the original TFP.
- Scalable Application Program Interface (API) - The Telecom C API wraps the telecom models into callable C libraries. The main functionality of this API is to enable effectively utilization of high-fidelity telecom models to support mission operation scenario simulations and design iterations. The telecom API allows external simulation programs like APGEN and MRNPT full control of the TFP and GTP to generate the link resources. A socket interface is currently being used by Virtual Mission [6] to remote access the TFP generic model on our server to support Team-X's pre-phase A science activity planning. The telecom API directly parallels the functionality of the standalone telecom analysis tools, including both the mission-specific models and generic models. The telecom API allows a user access to the telecom models via C callable routines, listed in Telecom API interface, by allowing the user to start a TFP or GTP session, set parameters, and run the TFP or GTP with the updated parameters. The TFP or GTP allows the user to run any allowable telecom configuration as defined by the mission. The API maintains a log file of all parameters modified using the API. The log file enables a user to re-generate the telecom scenario simulation to verify configuration and parameter settings for each run.
- MATLAB-to-C Compiler – A recent product from Mathworks, the MATLAB C/C++ Compiler, enables the translations of MATLAB subroutines into MATLAB-independent C/C++ source codes and executables. This provides an ideal development environment for scientific applications in which models and algorithms are developed in the powerful, flexible MATLAB environment. The resulting MATLAB codes are then converted to C/C++ source and executables for software configuration management and delivery.

4. DEVELOPMENT CHALLENGES

In the past few years, we have been successful to establish TFP as an operational multi-mission link analysis tool used by JPL and LMA telecom analysts. To make TFP a versatile and powerful tool for operation use, we have to overcome some of the challenges as described below:

Balance between vigorous Configuration Management (CM) and fast turn-around update

TFP and GTP are operational link analysis tools that generate formal data products for mission analysis and planning uses. As such, the TFP and GTP development are under vigorous CM control to ensure model and software consistency among users. The heavy CM control imposes rigid delivery schedule that is problematic to the continual and asynchronous nature of telecom model development and refinement. Telecom ground and spacecraft models are constantly being evaluated based on observable and calibration data from spacecraft telemetry as well as station measurement. It is essential to provide timely update to telecom models to support mission telecom planning, analysis, and trending activities. The solution to this dilemma is the "addpath" capability of the telecom tools, which allows advanced users to use new models created in his/her directory to override specific models, customize outputs, and/or add functionality without modifying the CM version. Permanent changes to the models are relayed to the developers and are incorporated for the next delivery.

Streamline usage of high-fidelity models

The TFP, UTP, and GTP represent JPL's highest fidelity link analysis tools. These tools provide accurate modeling of spacecraft and ground telecom performance behavior, as well as spacecraft and celestial dynamic simulations. Configuration of these modeling and simulation capabilities is usually complicated, and requires in-depth understanding of telecom system and its dependency on spacecraft trajectory and attitude. The TFP and GTP tools have a save state function that is a powerful feature of the GUI. When selected, it saves the current state of the GUI to a GUI state file (GSF) and allows a user to restore the simulation configuration in the future. In addition, a batch script is automatically generated. This batch script can be invoked from the MATLAB command line, performs the same analysis, and saves the results in a MATLAB data file. The save state function allows GUI settings of complicated link scenarios to be configured and saved in advance, and enables fast turn-around analysis by simply loading in the GSF into the GUI.

Allow standard input of spacecraft and celestial body dynamics but minimize dependency on these inputs using heuristic modeling

Telecom link capability and availability depends strongly on non-telecom factors like spacecraft trajectory, spacecraft attitude, and planetary ephemeris. The TFP and GTP use the standard NAIF SPICE interface to extract the ephemeris and attitude information of spacecraft and ground stations as well as the dynamic and geometric properties of the celestial bodies. Time-tagged spacecraft trajectory information is generally packaged in Spacecraft Planet Kernel (PSK) file, and orientation of the spacecraft bus frame is formatted in C-Kernel (CK) file. The location and orientation of the spacecraft antenna(s) with respect to the spacecraft bus frame is described in the form of a text file called Frame Kernel (FK). From the SPICE kernels, TFP and GTP compute the range between the spacecraft and the ground station, and the cone (degree–off-boresight) and clock (angle around the boresight) angles as a function of time. If C-kernels (and an associated antenna frame kernel) are not provided by the mission, the spacecraft attitude is determined from heuristics, either through the Custom Attitude GUI or by hard-coding specific heuristics. Heuristics are planned pointing strategies for different mission phases and safemode scenarios. In missions with an "Earth Pointed" heuristic, the spacecraft antenna points toward the Earth center and *not* toward a DSN site or station. A powerful feature added to TFP adaptations after 9/2001 is the ability to model a wide-variety of customized attitude heuristics through inputs to the Custom Attitude GUI[8]. Two styles of defining attitude are permitted: primary and secondary axis specification and Euler Angles representation. A subset of the Euler Angles representation, RA/Dec/Twist, is a natural means of representing the attitude of spinner spacecraft like Genesis, and can also be modeled by the customized attitude heuristics. TFP and GTP can also simulate simple spacecraft dynamics like spinning and rotating that are relevant to telecom. If the spacecraft is rotating, inputs for up to 2 different spin axes can be entered from the custom attitude heuristics GUI. The TFP and GTP rotate the initial orientation around the first spin axis, then around the (rotated) second spin axes. The spin axes are specified in the spacecraft body frame. The work in [2] describes in details a number of mission critical events that demonstrate how the combination of standard NAIF SPICE interface and heuristic modeling support telecom planning and analysis of the mission dynamic and critical events. Another new feature added to TFP and GTP development is the occultation model, which is particularly useful for orbital and surface missions like Odyssey and MER. The occultation model computes the in-view and out-of-view periods adjusted by light-time delay between communication elements as a function of the shape, size, and ephemeris of the celestial bodies in the solar system.

5. CONCLUSIONS

In this paper, we discuss the design principles and describe the development milestones and various challenges of an evolvable and extensible multi-mission telecom planning and analysis framework. This multi-mission framework has proven to be dependable and robust through its extensive use for mission support at JPL and at LMA. New capabilities on the modeling and simulation of inter-subsystem dynamic interaction are gradually phased in throughout the development. The effects on link performance due to celestial dynamics like planet rotations, ephemeris, and occultation, and spacecraft dynamics like attitude, trajectory, and fault protection strategies are accurately modeled within the telecom framework. Building upon the scalable and modular design, we extend the traditional point-to-point link analysis tools (e.g. TFP and GTP) to the system-wide Mars relay network planning and analysis framework. This framework models both link performance and network operation constraints, and support automatic and optimal Mars relay network planning and scheduling. We also initiated the generic TFP, the WEB-TFP, and the telecom API development to promote easy access to high-fidelity telecom models, and to support close-loop simulation with other systems and subsystems.

Along the theme of evolvable and extensible design, the next major milestone in the telecom planning and analysis tool development is to develop and integrate additional modeling components and interfaces to the telecom framework, and to transform the current link performance behavior modeling and simulation setup into a bit-level and symbol-level simulation framework. The new telecom models include Mars atmospheric propagation model, radio wave (RF) propagation model through plasma, and radio frequency interference model. The bit-level and symbol-level noise models and signal attenuation models enable analysis and simulation of the impacts of communication links to spacecraft and ground system and subsystem design. For examples, protocol design, error correction coding design and its performance evaluation, and compression algorithm design and its characterization in the presence of channel noise.

In closing, we discuss the lifecycle cost consideration of developing and maintaining subsystem software modeling and simulation. In the context of telecom, we try to answer the question: is it more cost effective for the telecom organization or for the software organization to be cognizant on the development and sustaining of telecom modeling and

[8] This feature is not available in all TFP adaptations, but is slowly being phased in. It will be included with all future TFP adaptations.

simulation software? To answer this question, we have to understand the evolving and changing nature of deep space communications. New communication techniques are constantly being introduced to the missions. For example, the Mars Exploration Rover (MER) is the first spacecraft to use the operational multiple spacecraft per antenna (MSPA) during its surface operation in 2004. The Mars Reconnaissance Orbiter (MRO) launched in 2005 will be the first to use turbo code and quadrature phase shift keying (QPSK), and to perform the operational Ka-band experiment. The Kepler Mission and other future missions plan to use Ka-band as its prime communication mode. On the ground side, new DSN and non-DSN antennas are being built, and existing non-DSN antennas are being employed to support spacecraft launch and tracking activities. Also spacecraft telecom performance and ground tracking performance are constantly being evaluated based on observable and calibration data from spacecraft telemetry as well as station measurement. It is essential to provide timely update to telecom models to support mission telecom planning, analysis, and trending activities. The overall design and ongoing sustaining effort requires close coordination between users and developers. It is much more difficult (and require a lot more effort) when the development organization does not have the domain knowledge and in-depth understanding on the right level of abstraction of telecom system behavior, and its interaction and dependency on other subsystems and the environment in different phases of the mission lifecycle.

Over the years, the multi-mission telecom tool development has expanded in scope, and evolves into a rather large-scale effort. From the start the design philosophy and development approach are dominant by engineers with telecom domain knowledge and mission support experience. Relevant requirements are factored into the early design. Since the tools are developed by telecom engineers who work closely with mission telecom system engineers, system analysts, and DSN operation personnel, information exchange on continual model refinement and software update is effective and accurate, this shortens development time, minimizes development error, and avoids unnecessary coordination and re-work.

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7. Biographies

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